

bearing. Each closed rotor loop [200] 202 is a planar short-circuited coil wound from thin niobium-titanium or niobium-tin wire or is formed from a similar superconductive material of a superconductive wire and mounted on one end of the rotor [shaft 201] 200.

In an initial state, the rotor 200 is prevented from rotation and is held in a fixed position with respect to stator 100 by arresting apparatus. Arresting apparatus may, in one embodiment of the invention, be a cylindrical member 203 having a conical aperture 2030 formed therein to receive a pointed end of rotor [shaft 201] 200 and initially hold rotor 200 in a non-rotational and fixed position with regard to stator 100. Other types and configurations of arresting apparatus may be devised within the spirit and scope of the invention to hold and release rotor 200 with respect to stator 100. In operation, cylindrical members 203 located at and engaging each end of the rotor [shaft 1000] 200 are moved outward along axis 1000 of rotor [shaft 201] 200 and away to disengage the conical apertures 2030 from the ends of rotor [shaft 201] 200. Rotor 200, in a manner herein after described in detail, is thereby released to move in a free stable state with regard to stator 100.

In order to prepare the bearing apparatus of Fig. 1 for operation, certain steps must be fulfilled. First rotor 200, Fig. 2, is held relative to stator 100 by the arrester members 203 gripping rotor [shaft 201] 200 after movement along axis 1000 while the bearing apparatus components are at room temperature T. When the room temperature T is maintained above the superconductivity transition temperature T_C , the closed stator loops 101 are symbolically shown as coils [102u] 101u connected to current terminals 152 and 153 with a two state switch 151 shown as connected across ones of the coils 101u. Similarly, each of the two closed rotor loops 202 positioned at an end of the rotor 200 are each symbolically shown as coils 202u coupled with another two state switch 251. The two bearing structures are each represented by the combination of the closed stator loop coils 101u and two-state switch 151 with the closed rotor loop coils 202u and two-state switch 251 located at each end of the rotor 200. At room temperature T, the two-state switches 151 and 251 are represented in a resistance state.

The closed stator loops 101, Fig. 1, of each bearing structure may be connected in series as shown in Fig. 2 with outer ends of one of the closed stator loop coils 101u connected to current terminals 152 and 153. Thus, a current may be applied from a current source to one terminal 152 and, at room temperature T, flow through coils 101u of the three closed stator loops 101 and return to the source by the other terminal [152] 153. In one embodiment of the invention, Fig. 3, although not necessarily limited thereto, two-state switch 151 may be constructed of a coil [10u] 1010u wound around part of a coil winding of ones of the closed stator loop coils 101u

and will operate in a manner hereinafter described in detail to assume states herein represented as a resistance and a short, respectively.

With the rotor 200 held in a fixed position with respect to stator 100 by arresting members 203, Fig. 4, the bearing apparatus is cooled by a cooling agent to a temperature T_1 below the superconductivity transition temperature T_C of the closed rotor and stator coil superconductor materials. With the superconductivity material of the closed stator and rotor loops, the resistance decreases as the temperature T_1 decreases and suddenly drops to essentially zero as temperature T_1 drops below the superconductivity transition temperature T_C . The electrical resistance of the closed rotor and stator loops 101, 202, Fig. 1, will remain at the zero value so long as the temperature condition T_1 is less than T_C for all parts of the closed loops. Thus, when temperature T_1 of the bearing apparatus is below the superconductivity transition temperature T_C , the resistance of the closed rotor and stator loop coils 202u and 101u, Fig. 4, is essentially zero and two-state switches 151 of the stator 100 and 251 of the rotor [100] 200 are shown as being in the short state.

As set forth in Fig. 3 of the drawing, a current I_1 is applied to the heating coil [10u] 1010u of two-state switch 151. The temperature of the section of coil winding 101u surrounded by heating coil [10u] 1010u rises above the superconductivity transition temperature T_C , Fig. 5, thereby causing the two-state switches 151 to assume the resistive state. Current I is then applied to the bearing apparatus via a current source 160 connected to the terminals 152 and 153 of the closed stator loops 101u while the temperature condition T_1 is less than T_C . In accordance with the superconductivity phenomenon, the superconductivity zero resistance of a small portion of the closed stator loops 101u are destroyed by the applied current I . Thus, a closed electrical circuit exists for the flow of an electric current. The applied current I and the flow of the applied current I in the closed stator loops [202u] 101u thereby generate a magnetic flux field between the adjacent closed stator and rotor coils [102u] 101u and 202u, respectively, attracting the closed rotor coils 202u to the closed stator coils [102u] 101u when the rotor coils 202u are positioned with respect to the stator coils [102u] 101u. The generated magnetic flux fields generate a current flow in the closed rotor loops 202u.

After achieving desirable energizing levels for the coils 101u of the closed stator loops 101, current I_1 , Fig.3, is removed from heating coils [10u] 1010u to discontinue the heating of the sections of closed stator loop coils 101u and the current I is removed from terminals 152 and 153, Fig. 6. Due to the cooling agent that is continuously cooling the bearing apparatus and the shut off of heating coils [10u] 1010u, the temperature T_1 is less than T_C and the zero electrical conductivity state as a consequence is restored to the closed stator loop coils 101u. The condition of two-state-switches 151 and 251 corresponds to the short state and in accordance with the

superconductivity phenomenon the current remains in the closed stator and rotor loops 101 and 202 and they begin to operate in a frozen magnetic linkage mode attracting one to the other without requiring any additional power.

Additional energizing of some of the closed stator loops may be required to provide for the fixed location of the rotor 200 after freeing, if needed. After that all of the closed stator and rotor loops 101 and 202 become short-circuited, Fig.6, the superconductive coils 101u and 202u operate in the frozen magnetic linkage mode with non-zero and non-equal frozen magnetic linkage for any pair of magnetically interacting closed stator and rotor loop 101 and 202. After final energizing of the closed stator and rotor loops 101 and 202, Fig. 1, sensors 300 mounted on the stator 100 measure magnetic fields parameters at fixed location of the rotor [100] 200. With the closed stator and rotor loops 101 and [102] 202 linked by the frozen magnetic linkages of the stator and rotor coils 101u and 201u, Fig. 7, and the two-state switches 151 and 251 in the short state, the arrester members 203 are moved outward along rotor axis 1000 to free rotor [shaft 201] 200, Fig. 1, thereby enabling rotor 200 to rotate in a positional equilibrium stable state with respect to stator 100 within the superconductive bearing structures defined by the magnetically linked and closed stator and rotor loops 101 and 202.

After freeing the rotor 200, the sensors 300 register changes of magnetic field parameters and a measuring subsystem that may be connected with the stator sensors 300 determines linear shifts and angular inclinations of the rotor 200 at its free locations compared with its fixed location relative to stator 100. If these shifts and inclinations surpass acceptable shifts and inclinations, the above steps may be repeated beginning with moving the arrester members 203 along rotor axis 1000 to engage the rotor [shaft 201] 200. After the required limitations of shifts and inclinations of the rotor 200 in its free equilibrium location are satisfied, the free rotor 200 may be rotated at various speeds within its operation range. For each rotor speed, additional energizing can be made to limit shifts and declinations for the revolving rotor 200 to acceptable deviations.

Another embodiment of the invention is shown in Fig. 8 of the drawing. The superconductivity bearing apparatus has a number of closed rotor loops 202 each wound as a coil of the superconductive wire or material around the rotor 201 and each positioned in a circular plane about the axis 1000 of the rotor 201. The stator 100 has a number of closed stator loops 101 each wound as a coil of superconductive wire 209 and ones of which are mounted in the stator 100 in a plane around the rotor adjacent to a corresponding one of the closed rotor loops 202. The closed stator loops 101 and rotor loops 202 are positioned in planes perpendicular to the rotor axis 1000 to form an axial plurality. Any pair of this plurality, or each superconductivity bearing, consists of six closed stator loops 101 and one closed rotor loop 202 positioned with the six

closed stator loops 101 surrounding the one closed rotor loop 202. Each closed stator loop 101 is a planar superconductive short-circuited coil wound from a thin niobium-titanium or niobium-tin wire 209 or constructed from other super conductive material. Closed stator loops 101 are equipped with the two-state-switch, Fig. 3, and encased in a rigid member mounted on stator 100. The planar closed stator loop 101 is configured by two non-equal circular arcs and two radial segments connected by smooth curves. Six closed stator loops 101 are equally angularly spaced in a plane parallel to the rotor axis 1000 such that each of the six closed stator loops 101 are equally distant from the axis 1000. Each closed rotor loop 202 is a ring superconductive short-circuited coil wound from the thin niobium-titanium or niobium-tin wire 209, or other superconductive material, and equipped with the two-state-switch, and encased in a rigid member which is mounted around the rotor shaft 201. In the structure, each superconductivity bearing has six of the closed stator loops 101 angularly positioned around one closed rotor loop 202 and are located in the same plane with other superconductivity bearing planes equally spaced along the rotor 201. In order to establish the operating conditions for this superconductivity bearing apparatus, the steps as earlier set forth for Figs. 2 through 7 are required.

In another embodiment of the invention, Fig. 9, each closed stator loop 101 is an identical coil encased in a rigid member mounted on stator 100 and wound from a thin superconductive niobium-titanium or niobium-tin wire 209 or other superconductive material and equipped with the two-state-switch, Fig. 3. The closed stator loops 101, Fig. 9, are each angular spaced and mounted on the stator between ones of the rotor closed loops 202 so as to be perpendicular to and off-center of the rotor axis 1000. Each closed rotor loop 202 is an identical short-circuited coil wound from a thin niobium-titanium or niobium-tin wire 209 or other super conductive material and encased in a rigid member attached to the rotor [shaft] 201 by a disk 207 positioned along the rotor axis 1000. In the arrested position of the rotor , the closed rotor loops 202 are concentric to the rotor axis 1000 and are equally axially spaced relative to adjacent closed stator loops 101. The operating conditions for this bearing apparatus are similar to the preferable embodiment of Fig. 1. In operation, frozen magnetic linkages are established between adjacent closed stator and rotor loops 101 and 202 thereby supporting a rotation of the rotor [200] 201 in an equilibrium stable and free state within the stator 100.

In yet another embodiment, superconductive bearing apparatus, in accordance with the principles of the invention, has a pair of superconductive magnetic bearings, Fig. 10. Each superconductive magnetic bearing is composed of three planer closed stator loops 101 adjacent one closed rotor loop 202 and may be used with a kinetic energy carrier for flywheel energy storage. The stator 100 comprises a pair of planar closed stator loops each having three coils wound of superconductive thin niobium-

titanium or niobium-tin wire or formed of other superconductive material and each coil angularly spaced adjacent to another one of the coils and each of three closed stator loops 101 mounted at an end of the stator 100 in a plane parallel to a corresponding one of the closed rotor loops 202 and each equipped with a two-state-switch, Fig. 3. Each closed stator loop 101, Fig. 10, is formed in a circular arc and two radial segments connected by smooth curves configuration and are equally angularly spaced in their plane and from rotor axis 1000. Closed rotor loops 202 are a ring configured superconductive short-circuited coil wound from superconductor wire and encased in a rigid member mounted in a plane perpendicular to the rotor axis 1000 on ends of the rotor 200 adjacent to three of the closed stator loops 101. The procedures for preparing this apparatus for operation are similar to above set forth procedures for the embodiment shown in Fig.1. In operation, frozen magnetic linkages are established between the three adjacent closed stator loops 101 and a closed rotor loop 202 thereby supporting a rotation of the rotor 200 in an equilibrium stable free state within the stator 100.

Closed loops as sources of magnetic fields can be represented in various design configurations. A pair of closed stator and rotor loops for use with a superconductive bearing rotor and stator shown in Fig.11 may be fabricated from a wide range of superconductor material. Generally they form concentric rigid thin current carrying rings 500. Rings 500 are formed in a three-layered plate wherein they are mounted in a heat sink 501 secured to a resistive heater 502 and attached to a backing 503. In another design, Fig. 12, a current carrying configuration is formed of a plurality of closed stator loops 500 each formed of a superconductive material configured to have two non-equal circular-arc sides joined at the ends thereof by radial segments and having zero electrical resistance at a temperature below a superconductivity transition temperature. Closed loops 500 are mounted in a circular configuration in a heat sink 501 which is secured on a resistive heater 502 attached to a backing 503 to form a closed loop network.

Fig. 13 illustrates another concept for the fabrication of closed loops. A thin layer of a resistive heater 502 is deposited on a flat backing 503. Next, a first heat sink 501, a thin layer of a good heat conductor like copper, is deposited on the resistive heater 502. Then a thin film of a semiconductor material such as a niobium-tin is deposited on the flat surface of heat sink 501 which is then etched to form a pattern of closed current carrying loops 500 as pluralities of individual closed curves and/or a rigid network with meshes of small width loops. After depositing the first layer of loops 500, a second heat sink layer 504 is deposited so that it fills all open areas and covers loops 500 providing a flat surface before next depositing the second layer of closed loops 500. Then a third heat sink layer 504 is deposited similarly to the second one. The layer sequence is repeated to form a "sandwich" of current

carrying closed loops of identical or unlike loops and with loop coincidence or not for neighboring layers of closed loops.

In any version of thin film technology, a closed loop 500 intended for mounting on a stator or rotor can be fabricated to include a current carrier, resistive heaters as two-state-switches, and with heat sinks. In one exemplary example, Fig.14, a plurality of closed loops 500, each formed of a superconductive material configured in a square configuration and having zero electrical resistance at a temperature below a superconductivity transition temperature, are formed as a "sandwich" of two webs of closed loops 500 having a square shape positioned in a mesh. First ones of the closed loops 500 are mounted as a square mesh on an upper surface of a first heat sink 504 and second ones of the closed loops 500 are mounted as a square mesh on an upper surface of a second heat sink 501 and mounted such that the second closed loops 500 are positioned adjacent a lower surface of the first heat sink 504 to correspond with the first closed loops 500.

Individual square multiple closed loops 500, Fig. 15, can be placed on heat sink 504 and configured in a micron size for typical micron superconductive bearing applications. The same scaling convention, Figs 16 and 17 may be used to form meshes of square and ring configured closed loops 500 of thin super conductive current carriers deposited on heat sinks 504.

Fig. 17 shows a design of individual ring current carriers 500 deposited on heat sink 504. Small sizes of closed loops in Figs. 15 through 17 promote the high rigidity of the magnetic bearing because rigidity is inversely proportional to sizes of current carriers. Fig. 18 shows large concentric closed rings 501 and small closed rings 500 between the large closed rings 501. Large concentric rings 501 configured as closed loops are responsible for providing large magnetic forces and small rings 500 are beneficial in providing high rigidity of a magnetic bearing. Fig.19 illustrates two neighboring layers 504 of closed loops 500 which overlap one another. Similar geometric configurations increases rigidity of superconductivity magnetic bearings due to overlapping of closed loops in layers of coils. The closed loop configurations set forth in Figs.15 through 19 may be utilized for the stator and rotor of superconductivity magnetic bearings.

A variety of sizes, forms and displacements of super conductive short-circuited loops can be used for the stator and rotor to provide specific magnetic force interaction in magnetic bearings. The closed loops geometry can satisfy high load requirements by special mutual displacements of magnetically interacting closed loops mounted on the stator and rotor. At the same time these mutual displacements must provide for the required properties of stable positioning and zero torque respective to the axis of the stator only. In other respects they can be arbitrary. Therefore, typical concentric mutual displacement is not necessary. The invention proposes two types of

the non-concentricity. In one case the non-concentricity is between axes of the stator and the magnetic field of the closed stator loops and in the second case between the axes of the stator and magnetic fields of the closed rotor loops. The non-concentricity loop arrangement provides for non-zero radial derivative of mutual inductance responsible for high rigidity. The invention also proposes special force regimes for magnetic forces in the superconductivity magnetic bearings in order to stretch or press the free rotor in axial and radial directions. These regimes may be utilized to establish conditions for providing for maximal rigidity of a superconductivity magnetic bearing.

Additional advantages may be achieved by adjustments of locations of the free rotor while it is in equilibrium and rotating to guarantee reliable performance over a range of speeds. Using magnetic field sensors, 300, Fig. 1, and a measuring subsystem, of a type well known and which needs not be shown for an understanding of the invention, can fulfill this adjustment. The sensors 300 are mounted on the stator and positioned in zones of the closed stator loop magnetic fields so that radial shifts of the rotor and angular declinations of the rotor axis are in functional relations with the sensors data in a one-to-one correspondence. As an example, the sensors 300 are located so that their axes of sensitivities are parallel to the stator axis and the rotor center of mass is between parallel planes containing the sensors 300. The number of sensors 300 positioned in each plane is three or more. Sensor data on the magnetic field parameters in each plane indicate the maximal radial rotor shifts in this plane. Data from sensors 300 in two planes are processed through the measuring subsystem to provide the means for accurate determination of radial shifts of the rotor center of mass and angular declinations.

While the foregoing detailed description has described several embodiments of superconductive bearing apparatus in accordance with this invention, it is to be understood that the above description is merely illustrative and does not limit the scope of the claimed invention. Particularly, the disclosed superconductive bearing apparatus may have various configurations of the stator and rotor in combination with various shapes and configurations of stator and rotor closed loops for establishing magnetic linkages supporting a rotation of the rotor in an equilibrium stable free state within the stator. It is obvious from the foregoing that the facility, economy and efficiency of bearing apparatus may be substantially enhanced by superconductive bearing apparatus for establishing magnetic linkages between closed stator and rotor loops forming a bearing supporting a rotation of the rotor in an equilibrium stable free state within the stator.

The section entitled Detailed Description of the Invention as above amended reads as follows:

In a first exemplary embodiment of the invention, superconductive bearing apparatus 10, in accordance with the principles of the invention, is shown in Fig.1 of

the drawing. The bearing apparatus 10 set forth in Fig. 1 has two magnetic superconductive magnetic bearing structures rotatably supporting a rotor 200 in a free state within a stator 100. Each bearing structure consists of three closed stator loops 101 and one closed rotor loop 202 wherein the cross section of each loop is small compared to the area of the planar loop. The closed stator loops 101, although not limited thereto, may be planar superconductive short-circuited coils wound from thin niobium-titanium or niobium-tin wire or similar superconductive material and are angularly mounted at ends of the stator around the closed rotor loops 202. Each closed stator loop 101, although not limited thereto, is configured to have two non-equal circular arc sides 1010 joined at the ends thereof by radial segments 1011. Three closed stator loops 101 are mounted in a plane at each end of the stator and are positioned 120° apart around a closed rotor loop 202 to form one superconductive bearing. Each closed rotor loop 202 is a planar short-circuited coil wound from thin niobium-titanium or niobium-tin wire or is formed from a similar superconductive material of a superconductive wire and mounted on one end of the rotor 200.

In an initial state, the rotor 200 is prevented from rotation and is held in a fixed position with respect to stator 100 by arresting apparatus. Arresting apparatus may, in one embodiment of the invention, be a cylindrical member 203 having a conical aperture 2030 formed therein to receive a pointed end of rotor 200 and initially hold rotor 200 in a non-rotational and fixed position with regard to stator 100. Other types and configurations of arresting apparatus may be devised within the spirit and scope of the invention to hold and release rotor 200 with respect to stator 100. In operation, cylindrical members 203 located at and engaging each end of the rotor 200 are moved outward along axis 1000 of rotor 200 and away to disengage the conical apertures 2030 from the ends of rotor 200. Rotor 200, in a manner herein after described in detail, is thereby released to move in a free stable state with regard to stator 100.

In order to prepare the bearing apparatus of Fig. 1 for operation, certain steps must be fulfilled. First rotor 200, Fig. 2, is held relative to stator 100 by the arrester members 203 gripping rotor 200 after movement along axis 1000 while the bearing apparatus components are at room temperature T . When the room temperature T is maintained above the superconductivity transition temperature T_C , the closed stator loops 101 are symbolically shown as coils 101u connected to current terminals 152 and 153 with a two state switch 151 shown as connected across ones of the coils 101u. Similarly, each of the two closed rotor loops 202 positioned at an end of the rotor 200 are each symbolically shown as coils 202u coupled with another two state switch 251. The two bearing structures are each represented by the combination of the closed stator loop coils 101u and two-state switch 151 with the closed rotor loop coils 202u and two-state switch 251 located at each end of the rotor 200. At room temperature T , the two-state switches 151 and 251 are represented in a resistance state.

The closed stator loops 101, Fig. 1, of each bearing structure may be connected in series as shown in Fig. 2 with outer ends of one of the closed stator loop coils 101u connected to current terminals 152 and 153. Thus, a current may be applied from a current source to one terminal 152 and, at room temperature T , flow through coils 101u of the three closed stator loops 101 and return to the source by the other terminal 153. In one embodiment of the invention, Fig. 3, although not necessarily limited thereto, two-state switch 151 may be constructed of a coil 1010u wound around part of a coil winding of ones of the closed stator loop coils 101u and will operate in a manner hereinafter described in detail to assume states herein represented as a resistance and a short, respectively.

With the rotor 200 held in a fixed position with respect to stator 100 by arresting members 203, Fig. 4, the bearing apparatus is cooled by a cooling agent to a temperature T_1 below the superconductivity transition temperature T_C of the closed rotor and stator coil superconductor materials. With the superconductivity material of the closed stator and rotor loops, the resistance decreases as the temperature T_1 decreases and suddenly drops to essentially zero as temperature T_1 drops below the superconductivity transition temperature T_C . The electrical resistance of the closed rotor and stator loops 101, 202, Fig. 1, will remain at the zero value so long as the temperature condition T_1 is less than T_C for all parts of the closed loops. Thus, when temperature T_1 of the bearing apparatus is below the superconductivity transition temperature T_C , the resistance of the closed rotor and stator loop coils 202u and 101u, Fig. 4, is essentially zero and two-state switches 151 of the stator 100 and 251 of the rotor 100 are shown as being in the short state.

As set forth in Fig. 3 of the drawing, a current I_1 is applied to the heating coil 1010u of two-state switch 151. The temperature of the section of coil winding 101u surrounded by heating coil 1010u rises above the superconductivity transition temperature T_C , Fig. 5, thereby causing the two-state switches 151 to assume the resistive state. Current I is then applied to the bearing apparatus via a current source 160 connected to the terminals 152 and 153 of the closed stator loops 101u while the temperature condition T_1 is less than T_C . In accordance with the superconductivity phenomenon, the superconductivity zero resistance of a small portion of the closed stator loops 101u are destroyed by the applied current I . Thus, a closed electrical circuit exists for the flow of an electric current. The applied current I and the flow of the applied current I in the closed stator loops 101u thereby generate a magnetic flux field between the adjacent closed stator and rotor coils 101u and 202u, respectively, attracting the closed rotor coils 202u to the closed stator coils 101u when the rotor coils 202u are positioned with respect to the stator coils 101u. The generated magnetic flux fields generate a current flow in the closed rotor loops 202u.

After achieving desirable energizing levels for the coils 101u of the closed stator loops 101, current I_1 , Fig.3, is removed from heating coils 1010u to discontinue the heating of the sections of closed stator loop coils 101u and the current I is removed from terminals 152 and 153, Fig. 6. Due to the cooling agent that is continuously cooling the bearing apparatus and the shut off of heating coils 1010u, the temperature T_1 is less than T_c and the zero electrical conductivity state as a consequence is restored to the closed stator loop coils 101u. The condition of two-state-switches 151 and 251 corresponds to the short state and in accordance with the superconductivity phenomenon the current remains in the closed stator and rotor loops 101 and 202 and they begin to operate in a frozen magnetic linkage mode attracting one to the other without requiring any additional power.

Additional energizing of some of the closed stator loops may be required to provide for the fixed location of the rotor 200 after freeing, if needed. After that all of the closed stator and rotor loops 101 and 202 become short-circuited, Fig.6, the superconductive coils 101u and 202u operate in the frozen magnetic linkage mode with non-zero and non-equal frozen magnetic linkage for any pair of magnetically interacting closed stator and rotor loop 101 and 202. After final energizing of the closed stator and rotor loops 101 and 202, Fig. 1, sensors 300 mounted on the stator 100 measure magnetic fields parameters at fixed location of the rotor 200. With the closed stator and rotor loops 101 and 202 linked by the frozen magnetic linkages of the stator and rotor coils 101u and 201u, Fig. 7, and the two-state switches 151 and 251 in the short state, the arrester members 203 are moved outward along rotor axis 1000 to free rotor 200, Fig. 1, thereby enabling rotor 200 to rotate in a positional equilibrium stable state with respect to stator 100 within the superconductive bearing structures defined by the magnetically linked and closed stator and rotor loops 101 and 202.

After freeing the rotor 200, the sensors 300 register changes of magnetic field parameters and a measuring subsystem that may be connected with the stator sensors 300 determines linear shifts and angular inclinations of the rotor 200 at its free locations compared with its fixed location relative to stator 100. If these shifts and inclinations surpass acceptable shifts and inclinations, the above steps may be repeated beginning with moving the arrester members 203 along rotor axis 1000 to engage the rotor 200. After the required limitations of shifts and inclinations of the rotor 200 in its free equilibrium location are satisfied, the free rotor 200 may be rotated at various speeds within its operation range. For each rotor speed, additional energizing can be made to limit shifts and declinations for the revolving rotor 200 to acceptable deviations.

Another embodiment of the invention is shown in Fig. 8 of the drawing. The superconductivity bearing apparatus has a number of closed rotor loops 202 each

wound as a coil of the superconductive wire or material around the rotor 201 and each positioned in a circular plane about the axis 1000 of the rotor 201. The stator 100 has a number of closed stator loops 101 each wound as a coil of superconductive wire 209 and ones of which are mounted in the stator 100 in a plane around the rotor adjacent to a corresponding one of the closed rotor loops 202. The closed stator loops 101 and rotor loops 202 are positioned in planes perpendicular to the rotor axis 1000 to form an axial plurality. Any pair of this plurality, or each superconductivity bearing, consists of six closed stator loops 101 and one closed rotor loop 202 positioned with the six closed stator loops 101 surrounding the one closed rotor loop 202. Each closed stator loop 101 is a planar superconductive short-circuited coil wound from a thin niobium-titanium or niobium-tin wire 209 or constructed from other super conductive material. Closed stator loops 101 are equipped with the two-state-switch, Fig. 3, and encased in a rigid member mounted on stator 100. The planar closed stator loop 101 is configured by two non-equal circular arcs and two radial segments connected by smooth curves. Six closed stator loops 101 are equally angularly spaced in a plane parallel to the rotor axis 1000 such that each of the six closed stator loops 101 are equally distant from the axis 1000. Each closed rotor loop 202 is a ring superconductive short-circuited coil wound from the thin niobium-titanium or niobium-tin wire 209, or other superconductive material, and equipped with the two-state-switch, and encased in a rigid member which is mounted around the rotor shaft 201. In the structure, each superconductivity bearing has six of the closed stator loops 101 angularly positioned around one closed rotor loop 202 and are located in the same plane with other superconductivity bearing planes equally spaced along the rotor 201. In order to establish the operating conditions for this superconductivity bearing apparatus, the steps as earlier set forth for Figs. 2 through 7 are required.

In another embodiment of the invention, Fig. 9, each closed stator loop 101 is an identical coil encased in a rigid member mounted on stator 100 and wound from a thin superconductive niobium-titanium or niobium-tin wire 209 or other superconductive material and equipped with the two-state-switch, Fig. 3. The closed stator loops 101, Fig. 9, are each angular spaced and mounted on the stator between ones of the rotor closed loops 202 so as to be perpendicular to and off-center of the rotor axis 1000. Each closed rotor loop 202 is an identical short-circuited coil wound from a thin niobium-titanium or niobium-tin wire 209 or other super conductive material and encased in a rigid member attached to the rotor 201 by a disk 207 positioned along the rotor axis 1000. In the arrested position of the rotor, the closed rotor loops 202 are concentric to the rotor axis 1000 and are equally axially spaced relative to adjacent closed stator loops 101. The operating conditions for this bearing apparatus are similar to the preferable embodiment of Fig. 1. In operation, frozen magnetic linkages are established between adjacent closed stator and rotor loops 101

and 202 thereby supporting a rotation of the rotor 201 in an equilibrium stable and free state within the stator 100.

In yet another embodiment, superconductive bearing apparatus, in accordance with the principles of the invention, has a pair of superconductive magnetic bearings, Fig. 10. Each superconductive magnetic bearing is composed of three planar closed stator loops 101 adjacent one closed rotor loop 202 and may be used with a kinetic energy carrier for flywheel energy storage. The stator 100 comprises a pair of planar closed stator loops each having three coils wound of superconductive thin niobium-titanium or niobium-tin wire or formed of other superconductive material and each coil angularly spaced adjacent to another one of the coils and each of three closed stator loops 101 mounted at an end of the stator 100 in a plane parallel to a corresponding one of the closed rotor loops 202 and each equipped with a two-state-switch, Fig. 3. Each closed stator loop 101, Fig. 10, is formed in a circular arc and two radial segments connected by smooth curves configuration and are equally angularly spaced in their plane and from rotor axis 1000. Closed rotor loops 202 are a ring configured superconductive short-circuited coil wound from superconductor wire and encased in a rigid member mounted in a plane perpendicular to the rotor axis 1000 on ends of the rotor 200 adjacent to three of the closed stator loops 101. The procedures for preparing this apparatus for operation are similar to above set forth procedures for the embodiment shown in Fig.1. In operation, frozen magnetic linkages are established between the three adjacent closed stator loops 101 and a closed rotor loop 202 thereby supporting a rotation of the rotor 200 in an equilibrium stable free state within the stator 100.

Closed loops as sources of magnetic fields can be represented in various design configurations. A pair of closed stator and rotor loops for use with a superconductive bearing rotor and stator shown in Fig.11 may be fabricated from a wide range of superconductor material. Generally they form concentric rigid thin current carrying rings 500. Rings 500 are formed in a three-layered plate wherein they are mounted in a heat sink 501 secured to a resistive heater 502 and attached to a backing 503. In another design, Fig. 12, a current carrying configuration is formed of a plurality of closed stator loops 500 each formed of a superconductive material configured to have two non-equal circular-arc sides joined at the ends thereof by radial segments and having zero electrical resistance at a temperature below a superconductivity transition temperature. Closed loops 500 are mounted in a circular configuration in a heat sink 501 which is secured on a resistive heater 502 attached to a backing 503 to form a closed loop network.

Fig. 13 illustrates another concept for the fabrication of closed loops. A thin layer of a resistive heater 502 is deposited on a flat backing 503. Next, a first heat sink 501, a thin layer of a good heat conductor like copper, is deposited on the

resistive heater 502. Then a thin film of a semiconductor material such as a niobium-tin is deposited on the flat surface of heat sink 501 which is then etched to form a pattern of closed current carrying loops 500 as pluralities of individual closed curves and/or a rigid network with meshes of small width loops. After depositing the first layer of loops 500, a second heat sink layer 504 is deposited so that it fills all open areas and covers loops 500 providing a flat surface before next depositing the second layer of closed loops 500. Then a third heat sink layer 504 is deposited similarly to the second one. The layer sequence is repeated to form a "sandwich" of current carrying closed loops of identical or unlike loops and with loop coincidence or not for neighboring layers of closed loops.

In any version of thin film technology, a closed loop 500 intended for mounting on a stator or rotor can be fabricated to include a current carrier, resistive heaters as two-state-switches, and with heat sinks. In one exemplary example, Fig.14, a plurality of closed loops 500, each formed of a superconductive material configured in a square configuration and having zero electrical resistance at a temperature below a superconductivity transition temperature, are formed as a "sandwich" of two webs of closed loops 500 having a square shape positioned in a mesh. First ones of the closed loops 500 are mounted as a square mesh on an upper surface of a first heat sink 504 and second ones of the closed loops 500 are mounted as a square mesh on an upper surface of a second heat sink 501 and mounted such that the second closed loops 500 are positioned adjacent a lower surface of the first heat sink 504 to correspond with the first closed loops 500.

Individual square multiple closed loops 500, Fig. 15, can be placed on heat sink 504 and configured in a micron size for typical micron superconductive bearing applications. The same scaling convention, Figs 16 and 17 may be used to form meshes of square and ring configured closed loops 500 of thin super conductive current carriers deposited on heat sinks 504.

Fig. 17 shows a design of individual ring current carriers 500 deposited on heat sink 504. Small sizes of closed loops in Figs. 15 through 17 promote the high rigidity of the magnetic bearing because rigidity is inversely proportional to sizes of current carriers. Fig. 18 shows large concentric closed rings 501 and small closed rings 500 between the large closed rings 501. Large concentric rings 501 configured as closed loops are responsible for providing large magnetic forces and small rings 500 are beneficial in providing high rigidity of a magnetic bearing. Fig.19 illustrates two neighboring layers 504 of closed loops 500 which overlap one another. Similar geometric configurations increases rigidity of superconductivity magnetic bearings due to overlapping of closed loops in layers of coils. The closed loop configurations set forth in Figs.15 through 19 may be utilized for the stator and rotor of superconductivity magnetic bearings.

A variety of sizes, forms and displacements of super conductive short-circuited loops can be used for the stator and rotor to provide specific magnetic force interaction in magnetic bearings. The closed loops geometry can satisfy high load requirements by special mutual displacements of magnetically interacting closed loops mounted on the stator and rotor. At the same time these mutual displacements must provide for the required properties of stable positioning and zero torque respective to the axis of the stator only. In other respects they can be arbitrary. Therefore, typical concentric mutual displacement is not necessary. The invention proposes two types of the non-concentricity. In one case the non-concentricity is between axes of the stator and the magnetic field of the closed stator loops and in the second case between the axes of the stator and magnetic fields of the closed rotor loops. The non-concentricity loop arrangement provides for non-zero radial derivative of mutual inductance responsible for high rigidity. The invention also proposes special force regimes for magnetic forces in the superconductivity magnetic bearings in order to stretch or press the free rotor in axial and radial directions. These regimes may be utilized to establish conditions for providing for maximal rigidity of a superconductivity magnetic bearing.

Additional advantages may be achieved by adjustments of locations of the free rotor while it is in equilibrium and rotating to guarantee reliable performance over a range of speeds. Using magnetic field sensors, 300, Fig. 1, and a measuring subsystem, of a type well known and which needs not be shown for an understanding of the invention, can fulfill this adjustment. The sensors 300 are mounted on the stator and positioned in zones of the closed stator loop magnetic fields so that radial shifts of the rotor and angular declinations of the rotor axis are in functional relations with the sensors data in a one-to-one correspondence. As an example, the sensors 300 are located so that their axes of sensitivities are parallel to the stator axis and the rotor center of mass is between parallel planes containing the sensors 300. The number of sensors 300 positioned in each plane is three or more. Sensor data on the magnetic field parameters in each plane indicate the maximal radial rotor shifts in this plane. Data from sensors 300 in two planes are processed through the measuring subsystem to provide the means for accurate determination of radial shifts of the rotor center of mass and angular declinations.

While the foregoing detailed description has described several embodiments of superconductive bearing apparatus in accordance with this invention, it is to be understood that the above description is merely illustrative and does not limit the scope of the claimed invention. Particularly, the disclosed superconductive bearing apparatus may have various configurations of the stator and rotor in combination with various shapes and configurations of stator and rotor closed loops for establishing magnetic linkages supporting a rotation of the rotor in an equilibrium stable free state within the stator. It is obvious from the foregoing that the facility, economy and